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Evaluation of acoustic radiation force on iron spheres in standing wave field

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1. Introduction

In micromachines and biotechnology, there is a need for technology for non-contact manipulation of small objects. We have been trying to trap small objects at nodes of sound pressure in standing wave fields using a single-axis acoustic levitator with two focused sound sources, which are arranged with small ultrasonic transducers used in ultrasonic distance meter and other divices [1-3].

In this study, we investigate the standing wave field formed in the single-axis acoustic levitator and evaluate the acoustic radiation force applied to a rigid sphere placed in the standing wave field.

2. Experimental apparatus

The ultrasonic transducers used in this study were cylindrical with a frequency of 40 kHz and a diameter of 10 mm × height of 7 mm. Two focused sound sources were fabricated by placing 36 of these transducers on a concave base with a radius of curvature of 70 mm, which was fabricated using a 3D printer. These two sound sources were placed above and below each other, and a short-axis acoustic levitation system was constructed in which the geometric focal points were coincident.

Fig. 1 shows the experimental apparatus. A 40.0 kHz sinusoidal wave generated by a function generator (NF circuit, WF1948) is amplified by an amplifier (YAMAHA, A-S301), and a voltage of about 10 to 40 V_{pp} is applied to the transducers to form a standing wave field between the sound sources. An iron sphere attached with a thread was placed in the center of the standing wave field. The top of the thread was connected to an electronic balance, and the weight of the iron sphere was measured.

3. Sound Field

The sound pressure distribution was measured using a microphone to evaluate the sound field. First, ultrasonic tone burst waves were emitted from the sound source, and the sound pressure distribution in the two-dimensional plane containing the sound axis was measured at intervals of 2 mm. Fig. 2(a) shows the sound pressure distribution (80 mm × 160 mm) measured with a precision measurement microphone (B&K, 4954A) from the sound source below. From this measurement, the ultrasonic waves are focused on the geometric focal point. However, since the diameter of this microphone is 1/4 inch (approximately 6 mm), which is not small compared to the wavelength of 8.5 mm, it is difficult to measure the exact sound field because it disturbs the standing wave field.

Therefore, we made a prototype needle-type microphone using a 1 mm diameter non-beveled needle, which is a needle without a sharp point, as a waveguide. The measurement results are shown in Fig. 2(b). Furthermore, the results of the measured sound pressure distribution in the 40 mm × 40 mm area using the needle-type microphone when two sound sources were driven in phase are shown in Fig.

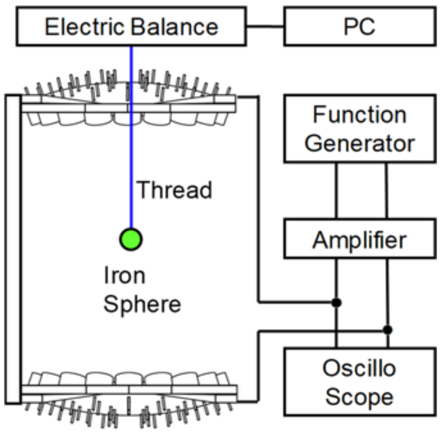

Fig. 1 Experimental apparatus.

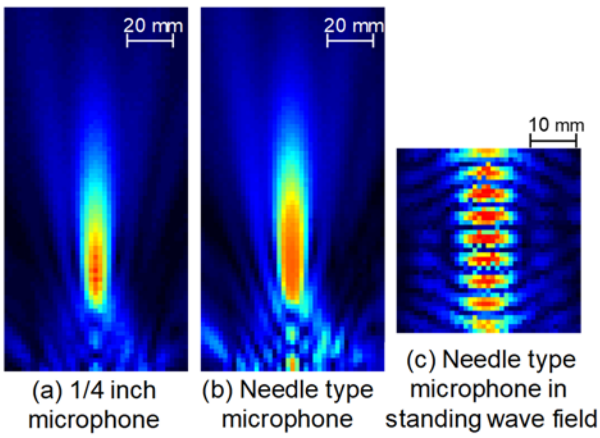

Fig. 2 Sound field measured with a 1/4-inch microphone and a needle-type microphone.

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2(c). The small variation in sound pressure is observed and a standing wave field is formed.

The results of measurements taken at 0.2 mm intervals along the central axis are shown in Fig. 3. A standing wave field is formed, with peaks or dips in the sound pressure repeating at intervals of approximately 4.3 mm, which is half a wavelength.

4. Acoustic radiation force on iron spheres

The weight of the iron spheres in the standing wave field was measured. Iron spheres with diameters of 3 mm to 7 mm were used. The iron spheres were suspended from an electronic balance, and the balance was reset to zero with no ultrasonic radiation. In other words, the change in weight due to the acoustic radiation force could be evaluated. Then, a continuous wave of ultrasonic radiation was emitted to form a standing wave field. Fig. 4 shows the change in weight when the phase of the sound source below is changed every 30°.

The iron sphere placed at the center of the standing wave field is subjected to acoustic radiation force from the pressure node to the pressure antinode. If the pressure node is above the iron sphere, the force acts to lift the iron sphere, so the weight of the iron sphere measured by the electronic balance becomes lighter. Conversely, if the pressure node is below the iron sphere, the weight becomes heavier.

For the 3 mm and 4 mm diameter spheres, the change in weight was almost the same. However, for the 5 mm to 7 mm diameter spheres, the change in weight was small. The nodes of the sound pressure form at half-wavelength intervals of 4.25 mm. When the diameter exceeds half-wavelength, it is thought that the force acting on the iron sphere becomes weak because the node and the antinode of the sound pressure are included in the iron sphere.

The sound pressure on the acoustic axis when the phase was changed every 90° are shown in Fig. 5. In Fig. 2 and Fig. 3, the sound pressure was measured using a tone burst wave, but in Fig. 5, it is a continuous wave. In the case of a continuous wave, the ultrasonic waves reflected from the opposite sound source surface will be superimposed, so when the phase difference is 0°, the superimposed ultrasonic waves will be in phase and the sound pressure will be high, but when the phase difference is 180°, the superimposed sound waves will be out of phase and the sound pressure will decrease.

5. Conclusion

The acoustic radiation forces acting on iron spheres in standing wave fields were evaluated. The sound pressure distribution in standing wave fields could be measured using a needle-type microphone. The acoustic radiation force acting on iron spheres in the standing wave field was measured using an electronic balance. For iron spheres smaller than half a wavelength, the force acting on them varied greatly depending on the phase. However, for iron spheres larger than half a wavelength, the force acting on them weakened.

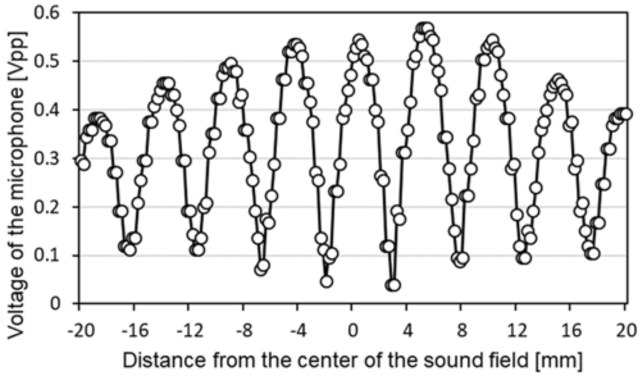

Fig. 3 Sound pressure along the sound beam axis.

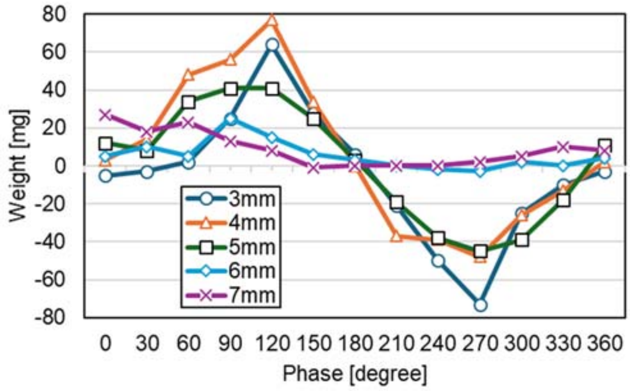

Fig. 4 Change in weight of iron spheres of 3−7 mm in diameter as a function of the phase difference.

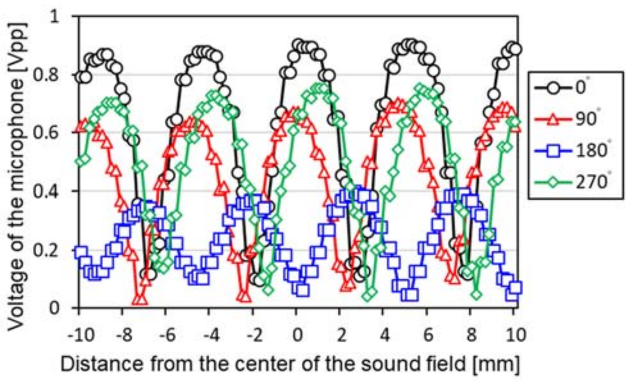

Fig. 5 Sound pressure on the sound axis for each 90° phase change.

References

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